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WEATHER AND SUGAR CANE IN LOUISIANA

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(NOTE.—This paper summarizes a much fuller discussion of the subject recently published in *The Planter and Sugar Manufacturer*, New Orleans, La. That discussion gave full tables of data, detailed statistical analyses, and a comprehensive discussion of practical field problems in which weather is a factor, together with numerous graphs. In the present summary, limitations of space prevent the inclusion of certain phases of the original paper, the full text of which may be obtained in pamphlet form on application to the journal named above.)

Sugar cane is a plant of tropical origin and its culture in Louisiana, near the climatic limit of production, is necessarily attended by increased climatic hazards. The fluctuations in weather conditions in this region, therefore, produce a larger effect upon yields, and this relation becomes an important subject of study. Slight tendencies toward persistence of favorable or unfavorable type of weather variations through a period of several years may be sufficient to afford or to destroy the margin of profit from the sugar crop in Louisiana, but these critical variations may be so obscured in the large annual fluctuations that the planters themselves do not become aware of the great influence of the prevailing weather upon their prosperity. However, by statistical analysis of the weather and crop records, the importance of the effects of weather changes upon cane yields are demonstrable.

Sugar cane differs from most other crops in that the desired yield is not produced directly from the harvest but from a manufacturing operation. Yields depend on several factors—tonnage of stalks, sucrose content of the cane, and purity of the juice—each of which is subject to more or less independent variation due to conditions during growth. The nature of sugar, a pure carbohydrate, gives warrant for assuming that besides the usual influence of rainfall and temperature upon the general development of the cane, there should be a large influence of sunshine upon the photosynthetic elaboration of sugar materials.

Data needed for examination of the problem of weather influences upon sugar production required extensive compilation of material. The State averages of precipitation and temperature could not be used, because sugar production is limited to about one-fifth of the area of Louisiana rather highly centralized in its south portion. Average monthly temperatures from three points, and average precipitation from 10 stations, with departures from normal, were computed for the sugar region covering the period from 1890 through 1924. The sunshine record after 1895 from New Orleans, near but to one side of the cane area, was used as the only available measure of that element, but this inadequately represented the true condition over the region as a whole. Some significant results, however, were obtained by using the New Orleans record.

It was necessary to secure the sugar yield records prior to 1911 in order to provide a 35-year series matching the weather records and permitting the use of correlation methods for statistical analysis. Total sugar produced has been recorded for each year, but unless this could be reduced to sugar per acre the data would be of little use in evaluating the weather influences because the total acreage of cane has been quite variable from year to year. From rare sources of information in New Orleans it was possible to construct yield tables showing acreage of cane, tonnage harvested, sugar produced per acre, sucrose content of the cane, and the ratio of sugar to molasses for practically every year from 1888 to 1924. This was the first published tabulation of these varied phases of sugar production in Louisiana for the years prior to 1911, when official Government estimates for the crop begin.

Examination of the records revealed two production periods in the 35 years covered, one for the first half of the series, in which average production of sugar was about 3,000 pounds per acre, followed by a sharp drop to yields averaging around 2,000 pounds per acre in the latter half. Preliminary analysis of the data by simply averaging the weather which marked contrasting groups of high-yield and low-yield years indicated that March temperatures were consistently involved in the differences in yields, as also appeared to be the rainfall of January preceding the crop.

Linear correlation was then applied to all the data. More than 100 monthly coefficients were computed to compare the relative influence of (*a*) monthly rainfall departures, (*b*) monthly temperature departures, and (*c*) monthly sunshine percentages upon (1) the sugar yield per acre, (2) the sucrose content of the harvested crop, and (3) the ratio of molasses to sugar produced. Many of these coefficients were, of course, so small as to lack any significance. On the other hand, four coefficients had a value in excess of ± 0.50 and 25 had values in excess of ± 0.25, many of these lying in groups of two to four adjacent months, with consistent signs. Such grouping appeared to add considerably to the probable significance of these coefficients.

The most significant monthly coefficients were as follows: March temperature correlated with sugar yield per acre gave a value of $+0.53$, which afforded a quantitative measure of the relationship previously found by preliminary graphic analysis. Likewise, the correlation of January rainfall and sugar yield produced a coefficient of -0.51, indicating that a dry January preceding the crop was almost as effective as a warm March in developing high yields. It was a matter of some surprise to find these significant values for weather and crop relations affecting months so far in advance of the season of most vigorous cane growth.

The highest value for this series was found in comparing August rainfall with the sugar content of the cane, this value reaching -0.54, and supported by three adjacent values for June, July, and September, all larger than −0.30. This group of values indicates strongly that a comparatively dry summer season increases the percentage of sugar in the cane. However, since the coefficients for rainfall of the same months against total sugar per acre were of small value, the increase in the percentage of sugar in the stalks due to drier summer weather must be accompanied by a reduction in the tonnage of the cane harvested, a condition favorable to the mill, because such a crop is more profitably handled and manufactured.

The last coefficient of this series with a value of +0.50 was found between the molasses/sugar ratio and November sunshine recorded at New Orleans. This value, relating to a month so near the harvest, can only be interpreted as a measure of a large influence of sunshine upon the ripening processes. Detailed investigation of a series of weekly milling results obtained from 13 years' harvests on a modern plantation near New Orleans further emphasized the probability that a decided ripening process usually takes place in November, and that this stage of development is considerably influenced by autumn sunshine.

During examination of the records in connection with the above studies, it was observed that the rainfall departures for the last half of each year were rather persistently below normal in the period when cane yields were high, and generally above normal in the later, low-yield period. This suggested that there might be a cumulative effect of the weather upon the growth and yield of cane. The nature of the cane plant, propagated by nearly continuous growth through vegetative reproduction, seemed to warrant the *a priori* assumption that up to a certain point there is an accumulation of the response of the crop to its environmental influences, especially under persistently favorable or unfavorable conditions, with impressed changes probably carrying forward with more effect because whole stalks bearing the stamp of a given set of conditions are planted and send up shoots for the next crop. Such cumulative effects would not appear in the correlations already discussed, as the lag in response and the longer period involved could not be brought into consideration.

To make an approach to the study of this probable effect upon sugar yields, a graphic method of comparison was devised. This method is an adaptation of the statistical curve known as the "ogive," to which attention as a tool of investigation in meteorological research has been called by Marvin [1], in connection with secular trends in climatic data. As finally adopted here it consisted of comparing *cumulative* rainfall departures for the seven-month period, July through the following January added year by year, with the *cumulative* annual departures of sugar yield and of the molasses/sugar ratio.

The rainfall curve in Figure 1, plotted for the period from 1890 through 1923, revealed remarkable similarity of trend as compared with the yield curves for the years 1891 through 1924, and traceable agreements in minor details further supported the major correspondence. Correlation of the rainfall and sugar yield curves gave the remarkably high coefficient of −0.70, more than eight times the probable error. This was considered a positive demonstration of a large influence of pre-season rainfall upon sugar yields and the general nature of the agreement strongly supported the assumption that the response of the crop to persistent tendencies in seasonal weather is cumulative to an important degree.

The decided trend in seasonal rainfall type, below normal during the first half of the 35 years studied and above normal thereafter, was roughly matched by a similar variation in temperature, revealed especially in the details of a tabulation of frost and freezing dates for 25 years, which indicated that cooler spring and warmer autumn in general marked the later, low-yield period as compared with the earlier period of higher yields.

It was concluded that this cumulative weather/crop relation operates through the seed cane, the more mature cane produced by longer growing season and drier ripening season reflecting its quality in improvement of yields from the succeeding crop. Conversely, late spring frosts shorten the growing season, and if accompanied by warm wet weather in the late summer and during autumn of the same year, the seed cane must be put down while still comparatively green and of low sugar content, this quality tending to reflect itself at once in diminished yield from the next crop. Given a succession of years with similar seasons, accumulation of the favorable or unfavorable response results until the maximum effect of the particular influence is reached. The demonstrated persistences of just such weather

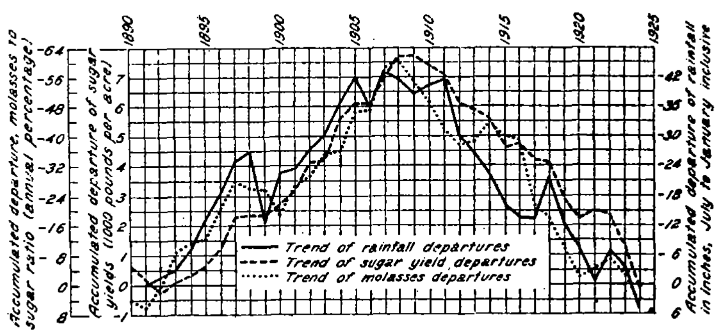

FIG. 1.—Relation of rainfall departures to departures of sugar yield and molasses yield, in southern Louisiana, 1890–1925

conditions are therefore presented as the most logical reason for the great difference in average yields from 1892 to 1908 as compared with the period after that year, ranging from 3,000 pounds per acre in the earlier to only 2,000 pounds per acre in the later period.

The direct influence of the weather upon sugar yields was found to be somewhat obscured by a reverse effect due to the influence of winter rainfall upon the infestation of cane by its principal insect enemy, the cane-borer moth. With 13 years' records of accurately estimated cane losses resultant from borer damage, the remarkably high correlation coefficient of −0.86 (±0.05) was obtained by comparing these losses (ranging from 9 to 30 per cent annually) with the rainfall departure for the six months from November through April. The size of that coefficient indicates that the rainfall over winter and in spring is a factor responsible for perhaps three-fourths of the fluctuation in cane-borer infestation. Obviously, this influence is directed oppositely to that of the winter rainfall upon cane quality, the insect pest being favored even as the cane crop is favored by drier winter conditions. Elimination of the weather/cane borer effects would therefore raise the value of the coefficients measuring the relation of rainfall to sugar yields.

As a test of the conclusions reached by correlation studies for Louisiana conditions, the rainfall of a number of tropical cane-producing regions was studied, data being assembled for widely separated areas in both the

[1] C. F. Marvin. Concerning Normals, Secular Trends, and Climatic Changes. Monthly Weather Review, 50:363.

northern and the southern hemispheres. These tropical regions were uniformly characterized by distinct wet and dry seasons. It seems reasonable to suppose that the evolutionary responses of cane, a plant of tropical origin, must be closely bound up with the rainfall regimen, seasonally the most variable climatic feature of its native habitat. The relative uniformity of rainfall through the year in the Louisiana cane region is very different from the marked seasonal distribution shown for tropical areas. In Louisiana any variation from normal rainfall tending toward closer approximation to its seasonal character in the tropics is therefore favorable to cane, while that variation is unfavorable which produces or tends toward a uniformity of rainfall.

These considerations support and clarify the meaning of the high correlation found between seasonal rainfall and sugar yield in Louisiana.[2] Those years or terms of years when Louisiana rainfall most closely approximated the seasonal type of the Tropics, with accentuation of wet and dry seasons produced the best yields. In Louisiana increased rainfall during spring until June, and rainfall below normal from August through harvest, produces such an accentuation and increases yields, whereas years or periods of more uniformly wet character, or with the seasonal type reversed, reduce yields.

[2] Tengwall and van der Zyl have found, in Java, a high degree of correlation between seasonal rainfall and the yield of sugar from cane.

THE TROPICAL STORM OF AUGUST 25-26, 1926, IN SOUTHERN LOUISIANA

551.515 (763)

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This paper, supplementary to the regular report on warnings, New Orleans forecast district, for August, 1926, considers some aspects of the hurricane which have been brought out through further study.

Advance indications of tropical storms are usually provided by the tides and the clouds. As this storm, while in the southern part of the Gulf of Mexico, was apparently small and of moderate intensity, the advance tides were not alarmingly high on the coast. At Burrwood the tide was 0.5 foot above the predicted tide on the 23d and rose slowly during the ensuing 48 hours to a maximum 1 foot above the predicted tide at 11 a. m. of the 25th. Along the coast of Terrebonne Parish slightly higher advance tides were reported, but there are no gage readings for this section.

At Galveston the tide was 2 feet above the predicted tide in the afternoon of the 25th, or 1 foot above the highest reading of the preceding day. This was a local effect, due to the 20 to 30 mile north wind, which favored a moderate accumulation of water in the southern end of Galveston Bay, the escape of water into the Gulf being retarded somewhat by the narrowness of the passes separating the Bay from the Gulf. The moderate southeast swells also tended to increase the tide slightly.

The clouds at middle altitudes, alto-stratus and occasionally alto-cumulus, came from the south at New Orleans nearly all day on the 24th and until 1 p. m. of the 25th, when they became obscured by lower clouds from the southeast and east. During this time the direction of the middle clouds was more changeable at Pensacola and Mobile; both upper and middle clouds were occasionally observed moving from the south and also from southwest, west, and northwest. At Galveston cirrus and cirro-stratus clouds from the south and southeast prevailed during the morning of the 24th, but from westerly directions in the afternoon of the 24th, in agreement with the highest clouds over New Orleans and farther east. In the afternoon of the 25th, when the storm front was advancing to the Louisiana coast, alto-cumulus clouds at Galveston were moving from the north, directly opposite to the movement of middle clouds at New Orleans, as observed up to 1 p. m.

The movement of alto-stratus over eastern Louisiana, considerably in advance of the storm, shows an air current from the south. The northward movement of cirrus clouds over Galveston during the morning of the 24th, and over Port Arthur in the afternoon, appears to have come from the region of the storm, although east of Galveston not many observations of cirrus from the direction of the storm were obtained, the directions indicating a prevailing eastward movement at the cirrus level. The movement of cirrus from southerly directions possibly took place at a lower level than the prevailing cirrus movement from the west. Before the sky became completely overcast with lower clouds, alto-cumuli from the south were noted at Mobile in the early morning of the 25th and alto-stratus clouds from the south at Pensacola in the early afternoon. The width of the northward-moving current was not great and its thickness is unknown; but apparently there was sufficient movement to guide this relatively small hurricane in its advance to southeastern Louisiana.

In approaching the coast the storm was evidently moving north-northeast. Ship Shoal Lighthouse, latitude 28° 54′ 52″ N., longitude 91° 4′ 15″ W., was in the western part of the central calm area at 4 to 5 p. m. of the 25th, with lowest barometer reading (uncorrected) of 28.30 inches, the wind changing through north to west and increasing to hurricane force after the passage of the storm center. Soon after the center passed inland the storm curved to the northwest. The path of the center lay west of the Mississippi River, approaching it rather closely at Donaldsonville and Plaquemine (pressure of 29.16 inches at Plaquemine) and crossing the Atchafalaya River in northwestern Iberville Parish.

Among the influences tending to cause the storm to turn westward in Louisiana we may mention a rise in pressure over Tennessee and northern Alabama and Georgia in the afternoon of the 25th, which, with the relatively high pressure on the west, formed a barometric ridge extending east and west and favored a circulation of air which would tend to drag the storm westward. In an eastward-moving extratropical storm a rise in pressure in front of it has a blocking or retarding effect; in a northward-moving storm the effect appears to be as stated in the present instance, although exceptions may occur when the dominant circulation is not indicated by the surface observations.

The remarkable intensity of the storm, as indicated by the low barometer readings at Houma, compared to those at other stations, was referred to in the preliminary report. The aneroid barometers used at Houma and Morgan City have been tested at New Orleans for readings as low as 28 inches, enabling us to make necessary corrections. The pressure at Houma fell 1.32 inches in 11 hours, at an average rate of 0.12 inch an hour. From 5 p. m. to 9.30 p. m., the rate of fall was 0.32 inch an hour, about the same as that registered at New Orleans in the